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(71) Applicant: GENERAL ELECTRIC COMPANY [US/US]; 1 River Road, Schenectady, NY 12345 (US).

(72) Inventors: WILLIAMS, Rick, N.; 63 Eric Drive, Pittsfield, MA 01201 (US). POSLINSKI, Andrew, Joseph; 20 Glade Drive, Schenectady, NY 12308 (US). KAMINSKY, John; 54 Van Dyke Drive South, Rensselaer, NY 12144 (US). SHULER, Stephen; 1919 North Bissell Street, Chicago, IL 60614 (US). ABBATIELLO, Nick; 46 Bruce Drive, Dalton, MA 01226 (US). CHATI, Mandar; Apartment #1B8, 1187 Hillside Avenue, Niskayuna, NY 12309 (US). LEMONDS, Jeff; 1 Fox Glen Court, Clifton Park, NY 12065 (US). MORRIS, Garron, K.; 882 Warner Road, Niskayuna, NY 12309 (US).

(74) Agents: CHASKIN, Jay, L. et al.; General Electric Company, 3135 Easton Turnpike W3C, Fairfield, CT 06431 (US).

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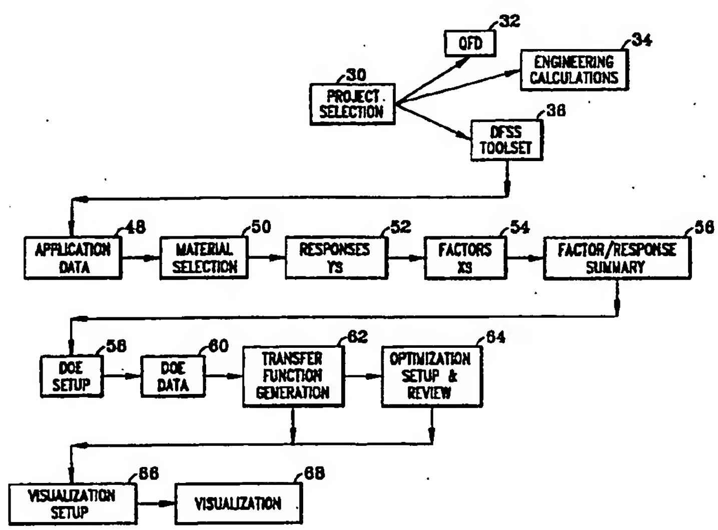
(54) Title: METHOD, SYSTEM AND STORAGE MEDIUM FOR EVALUATING A PRODUCT DESIGN



(57) Abstract: An exemplary embodiment of the invention is a method for evaluating a product design. The method includes specifying a plurality of factors (44) related to the product and specifying a plurality of responses (46) affected by said factors. A design of experiments routine is performed to generate design of experiments data relating factors to the responses. Regression is performed to generate a transfer function in response to the design of experiments data. The transfer function is optimized in response to user-defined optimization criteria to generate an optimized factor and an optimized response. The optimized factor and optimized response are then displayed.

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METHOD, SYSTEM AND STORAGE MEDIUM FOR EVALUATING A PRODUCT DESIGN

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. provisional patent application 60/162,388 filed October 29, 1999, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

The invention relates to a method and system for evaluating a product design. The task of generating, evaluating and implementing a product design is a formidable one. Typically, product designs are generated by design personnel and put through a process often referred to as design review. In design review, individuals skilled in design, production, inspection, packaging, etc. evaluate designs. This often leads to re-design and further design review cycles delaying new product introduction. Once a product design is selected, prototypes may be produced using different materials and/or manufacturing processes. Although the selection of materials and manufacturing processes is performed by those skilled in the art, this process is still an iterative trial and error process that often results in changes to the design accompanied by additional prototyping. This cycle delays new product introduction and is often focused on internal metrics rather than customer metrics.

A product design may be represented by product factors (e.g., material, processing parameters, dimensions) that affect product responses (e.g., cost, performance). The factors and responses define a design space. Much of the above-described iterative cycle conventionally performed in the art is an attempt to locate a region in the design space in which product factors and product responses are within desired limits or constraints. Thus, there is a need in the art for a system that

accelerates the design process by allowing a designer to determine areas in the design space meeting design criteria.

BRIEF SUMMARY OF THE INVENTION

An exemplary embodiment of the invention is a method for designing a product. The method includes specifying a plurality of factors related to the product and specifying a plurality of responses affected by said factors. A design of experiments routine is performed to generate design of experiments data relating at least one factor to at least one response. Regression is performed to generate a transfer function in response to the design of experiments data. The transfer function is optimized in response to user-defined optimization criteria to generate an optimized factor and an optimized response. The optimized factor and optimized response are then displayed.

Another exemplary embodiment is a system for designing a product. The system includes an interface for receiving a plurality of factors related to the product and a plurality of responses affected by the factors. A design of experiments module performs a design of experiments routine to generate design of experiments data relating at least one factor to at least one response. A regression module performs regression to generate a transfer function in response to the design of experiments data. An optimization module optimizes the transfer function in response to user-defined optimization criteria to generate an optimized factor and an optimized response. A visualization module displays the optimized factor and the optimized response.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is flowchart of a process for designing a product in an exemplary embodiment of the invention;

FIG. 2 is a block diagram of a system for designing a product;

FIG. 3 depicts an exemplary interface to an engineering design calculator;

FIG. 4 depicts an exemplary interface for entering application factors;

FIG. 5 depicts an exemplary interface for selecting materials;

FIG. 6 depicts an exemplary interface for entering responses;

FIG. 7 depicts an exemplary interface for entering manufacturing factors;

FIG. 8 depicts an exemplary factor/response summary;

FIG. 9 depicts an exemplary interface with a DOE module;

FIG. 10 depicts exemplary design of experiments data;

FIG. 11 depicts an exemplary interface for optimization;

FIG. 12 depicts an exemplary interface for setting up a visualization;

FIG. 13 depicts an exemplary visualization for two materials.

DETAILED DESCRIPTION OF THE INVENTION

An exemplary embodiment of the invention is a method and system for designing a product. As used herein, product is intended to have a broad meaning encompassing a variety of items. Specific examples of product designs are provided, but do not limit the scope of the invention. FIG. 1 is a flowchart of a process for

designing a product and FIG. 2 is a block diagram of a product design system shown generally at 10. As the user goes through the process shown in FIG. 1, parts of the product design system 10 are utilized as described herein. As shown in FIG. 2, the product design system 10 includes a number of modules for performing certain functions during the design process.

Shown in FIG. 2 are a quality function deployment (QFD) module 12, an engineering design calculator 14, a design of experiments (DOE) module 16, a regression module 20, an optimization module 22 and a visualization module 24. Each module may be implemented through a software application implemented by a general purpose computer. The modules may be implemented on a single general purpose computer and accessed by the user through a user interface 26. Alternatively, the modules may be implemented on a plurality of general purpose computers remotely located from each other. The user interface 26 may access the various modules over a network 27 such as a local area network (LAN), wide area network (WAN), global network (e.g., Internet), etc. The modules may be implemented on computers which act as servers for multiple client computers. The user interface may include a user interface application (e.g., web browser) or interfacing with one or more servers that execute software applications corresponding to the modules shown in FIG. 2.

Referring to FIG. 1, the process for designing a product will now be described. The process begins at step 30 where the user selects a desired task such as quality function deployment (QFD) at step 32, engineering calculations at step 34 or use of a design for six sigma (DFSS) toolset at step 36. If the user selects QFD at step 32, the QFD module 12 is accessed. The QFD module 12 allows the user to perform a quality function deployment process in which process variables or product design parameters (often referred to as key control parameters (KCPs) or factors) are analyzed to determine effects on critical to quality parameters (CTQs) or responses.

The use can define CTQs and determine the effect that KCPs have on CTQs. Conventional QFD applications software may be used to allow the user to define CTQs and analyze the interaction between KCPs and the CTQs.

If the user selects engineering calculations at step 34, the engineering design calculator 14 is accessed. The engineering design calculator 14 allows the user to execute calculations for a single set of conditions. FIG. 3 depicts an exemplary interface to the engineering design calculator 14 which is directed to performing calculations related to molding of plastic components. The engineering design calculator 14 allows the user to select material through a select material icon 40. This connects the user to a database of plastics which includes parameters of the plastics such as cost, hardness, etc. The user can select different materials to view the effect that different materials have on certain responses or Y's. The user can also select a geometry for the molded plastic component as shown at geometry selection option 42.

The user then enters values 45 for factors 44 (or X's) related to the plastic component and the molding process. The values 45 are then used to compute responses 46 (or Y's) which provide information such as cycle time and cost to the user. The calculations which derive the responses 46 from the factors 44 are based on predetermined functions. The engineering design calculator 14 performs calculations based on a single set of factors 44. Thus, for the user to see the effect of a change in a factor 44 (e.g., mold temperature) on a response 46 (e.g., total cost), the user must change the value 45 of a factor 44 and recalculate the responses 46. Thus, the engineering design calculator is used to generally determine the effect of factors 44 on responses 46, but more robust tools are used, as described herein, to optimize one or more responses 46.

If the user selects DFSS toolset at step 36, the process flows to step 48 where the user enters application factors concerning the product to be manufactured. The

application factors define the product to be manufactured and generally will not vary with materials or processing parameters. FIG. 4 depicts an exemplary user interface for entering the application factors. As shown in FIG. 4, the user can select a geometry at geometry selection area 70 and can specify values 73 for application factors 72. The application factors shown in FIG. 4 are directed to a plastic part. It is understood that other types application factors may be used given the application and the invention is not limited to plastic components.

At the application factor entry step 48, the user can also enter statistical data in addition to the value 73 for each application factor 72. As shown in FIG. 4, the user can enter a standard deviation 74, a low limit 76 and a high limit 78 for each application factor. One or more of the statistical data may be used in the design of experiments process described herein. The user can specify that an application factor 72 be used in a design of experiments (DOE) by checking a design of experiments indicator 80. Typically, the user enters a low limit 76 and/or a high limit 78 if an application factor is to be used in a design of experiments. The application factors 72 may also include one or more user-defined application factors 82. Several of the application factors 72 are predefined. The user-defined application factors 82 allow the user to enter an application factor that is not provided for in the predetermined application factors and have this user-defined application factor 82 considered in a subsequent design of experiments.

Once the application factors 72 have been entered, flow proceeds to step 50 where the user selects a material to be used in forming the product. FIG. 5 is an exemplary interface for selecting materials. The user can identify a material through a select material icon 86 which may direct the user to a database of commercially available materials. If the user selects a commercially available material, the material characteristics (cost, hardness, melt temperature, etc.) are contained in the database and are accessible during later stages of the design process. The engineering design

calculator 14, described above, may be used to help the user select appropriate materials for a particular application by providing responses 46 for a given material. Instead of selecting a predefined material, the user may define characteristics of a material that is not commercially available. For example, the user may define a custom material by entering material characteristics (cost, hardness, etc.) that are not realized by any commercially available material. This allows the user to design a product based on non-existing materials and evaluate whether the expense in generating the custom material is warranted.

Once the user has selected a material, either predefined or user-defined, at step 50, flow proceeds to step 52 where the user enters responses. FIG. 6 is an exemplary interface for entering responses 90. The responses 90 represent parameters that the user may want to control or optimize. For each response, the user can enter statistical data including a low limit 92, a target value 94 and a high limit 96. The low limit 92, target value 94 and/or high limit 96 may all be used in the design of experiments process described herein. The user can also define a type of optimization to be performed on a response 90 through an optimization indicator 98. As described herein, the system can determine factors so that one or more responses are optimized. The optimization indicator 98 allows the user to define the type of optimization (e.g., minimize, maximize, meet a target value, etc.). The user can designate that a response 90 be used in a subsequent design of experiments process by selecting a design of experiments indicator 100. The responses 90 may also include one or more user-defined responses 102. Several of the responses 90 are predefined. The user-defined responses 102 allow the user to enter a response that is not provided for in the predetermined responses and have this user-defined response 102 considered in the design of experiments and optimization steps described herein. The responses shown in FIG. 6 are directed to a molding a plastic part. It is understood that other types of responses may be used given the application and the invention is not limited to plastic components.

Once the user has defined responses 90, predefined and/or user-defined, at step 52, flow proceeds to step 54 where the user enters manufacturing factors. FIG. 7 depicts an exemplary user interface for entering the manufacturing factors 108. The manufacturing factors 108 represent factors in the manufacturing process that may be controlled or modified. The user can specify a value 109 for manufacturing factors 108. The user can also enter statistical data in addition to the value 109 for each manufacturing factor 108. As shown in FIG. 7, the user can enter a standard deviation 110, a low limit 112 and a high limit 114 for each manufacturing factor 108. One more of the statistical data may be used in the design of experiments process described herein. The user can specify that a manufacturing factor 108 be used in a design of experiments (DOE) by checking a design of experiments indicator 116. Typically, the user enters a low limit 112 and/or a high limit 114 if a manufacturing factor is to be used in a design of experiments. The manufacturing factors 108 may also include one or more user-defined manufacturing factors 118. Several of the manufacturing factors 108 are predefined. The user-defined manufacturing factors 118 allow the user to enter a manufacturing factor that is not provided for in the predetermined manufacturing factors and have this user-defined manufacturing factor 118 considered in a subsequent design of experiments. The manufacturing factors shown in FIG. 7 are directed to a plastic molding process. It is understood that other types manufacturing factors may be used given the application and the invention is not limited to manufacturing of plastic components.

Once the manufacturing factors, predefined and/or user-defined, have been entered at step 54, flow proceeds to step 56 where the user is presented with a factor/response summary such as that shown in FIG. 8. As shown in FIG. 8, the factor/response summary includes application factors 72, user-defined application factors 82, manufacturing factors 108 and user-defined manufacturing factors 118. In addition, miscellaneous or other factors 122 may also be included which do not correspond to the categories of application factors, user-defined application factors,

manufacturing factors and user-defined manufacturing factors. The term factors, as used herein, is intended to have a broad meaning and is not limited to the particular examples or categories described above. Instead of progressing through steps 48, 50, 52 and 54, a user may proceed directly to step 56 and enter factors and responses as described above. Steps 48, 50, 52 and 54 are directed to a limited set of factors or responses and may help focus the user on specific aspects of the application. An experienced user, for example, may proceed directly to step 56 and enter factors

The ability to enter user-defined application factors, user-defined materials, user-defined responses and user-defined manufacturing factors allows the system 10 to simulate manufacturing of products based, in part, on hypothetical, user-defined data. The factors, materials and responses, and their interrelationships may be defined based on existing simulation designs, empirical data, scientific analysis (e.g., thermodynamics, physics) and hypothetical, user-defined data. This provides a powerful tool for the designer in that user-defined data can be entered along with established data. The design of experiments, transfer function generation and optimization, described herein, is performed in response to the user-defined data.

The factor/response summary also includes responses 90 and user-defined responses 102. As shown in FIG. 8, a value 126 may be calculated for responses 90 and user-defined responses 102. The calculations are performed by the engineering design calculator 14. This provides the user with a general indication of how factor values effect response values. If the user wants to determined how changes in a factor effect a response, the user must alter the value of a factor and instruct the engineering design calculator to recalculate the responses. The user may view the factor/response summary and determine that certain responses (e.g., total cost) are too far from desired values and return to prior steps, such as material selection to effect the response. To optimize responses, more sophisticated tools are used as described herein.

Once the user is satisfied with the factor/response summary provided in step 56, flow proceeds to step 58 where the design of experiments routine is initiated. FIG. 9 depicts an exemplary user interface with the DOE module 16 for initiating a design of experiments. The DOE module 16 is a design of experiments software application as described above. The DOE module 16 may be implemented using commercially available design of experiments software applications. As shown in FIG. 9, the user sets up the design of experiments by selecting a DOE type through DOE type icons 130. The user can select a default DOE, launch a DOE advisor to help select the appropriate DOE or specify a custom DOE. The user is also presented with an identification of the materials 132, factors 134 and responses 136 that are to be considered in the design of experiments as selected by the user through DOE indicators.

Once the design of experiments has been setup in step 58, flow proceeds to step 60 where the design of experiments data is generated. The DOE module 16 performs the design of experiments process to generate design of experiments data. FIG. 10 depicts exemplary design of experiments data. For each material 132, the design of experiments module 16 perturbs the factors 134 to assume values within a range defined by a low limit and a high limit and obtains values for responses 136. The low limit and high limit may be taken from the appropriate application factors or the manufacturing factors entered by the user through steps 48 and 54, respectively. Design of experiments data is generated for each material 132 identified in the DOE setup step 58. For each material, a design space is generated corresponding to the relationship between factors and responses.

To perform the DOE and compute the values for responses 136, the user can select a Perform DOE icon 137. This initiates the DOE process in which values are determined for each response 136. The user can also select a portion of the DOE data for computation of values by selecting the Perform Area icon 139. The user can then

select a subset of the DOE data (e.g., lines 1-3) and determined values for responses 136 for only this subset of DOE data. The DOE module determines the values for responses 136 by calling one or more other application modules. For example, the Melt Pressure to Fill may be calculated by an engineering design module 17 (e.g., software application) that is initiated by the DOE module16. The engineering design module 17 returns the value for Melt Pressure to Fill and this value is added to the DOE data. The Total Cycle Time may be derived by another software module such as a molding simulation module 19. The modules used to derive values for responses 136 may have access to all the factors provided by the user. The modules called by the DOE module 16 to obtain values for responses can be established by the user or a system administrator. Alternatively, certain DOE responses 136 are determined by experimental data and thus, the user must enter the responses 136 based on experimental data.

Once the design of experiments process is completed, flow proceeds to step 62 where one or more transfer functions are generated which mathematically relate the factors 134 to responses 136 for each material 132. The regression module 20 performs regression on the design of experiments data to generate the transfer functions which mathematically relate the factors 132 to the responses 136 for each material. The transfer functions may bє stored in a transfer function database 21 for use in subsequent applications.

Once the transfer functions are generated, flow proceeds to step 64 where optimization is performed. Optimization is performed by optimization module 22. The user defines the type of optimization through a user interface such as that shown in FIG. 11. For a given material 132, the user can optimize one or more responses 136 in multiple ways using an optimization indicator 98. In addition, the user can enter low limit 92, target value 94, high limit 96 as described above with respect to FIG. 6. These values may be carried over from step 52 where the responses 136 were

identified by the user or modified by the user. For example, as shown in FIG. 11, the user has indicated that the Melt Pressure to Fill to be minimized, the Cycle Time be a predetermined target value and the Total Cost be minimized. The optimization module 22 uses the transfer functions generated by the regression module 20 and determines the appropriate values for factors 134 to optimize the responses 136 as identified by the user. In addition, the optimization module 22 can determine statistical factors such as defects per million opportunity (DPMO) 150. A defect occurs when a response value exceeds an upper or lower limit. The DPMO value can be used to generate a Zst value which is commonly used in the six sigma design process to evaluate designs. Based on normal distributions, a DPMO value of 3.4 equals a Zst score of 6 meaning that the design meets the six sigma quality standards.

Additional constraints 152 on the optimization can entered which will impose further limits on the optimization beyond those defined by optimization indicators 98. For example, the user may specify that the product of Mold Temperature and Melt Pressure to Fill be less than a predetermined value. The user enters this constraint in the additional constraints field 152 by entering a mathematical representation of the constraint and selecting a optimize indicator 154. The constraint serves as a boundary in the design space preventing the optimization mod .le from producing a solution that violates the constraint.

Additional optimization may be performed through the other optimization field 160. The optimization performed on responses 136 assumes that all three responses are equally important to the user. The other optimization field 160 allows the user to assign a weight to one or more responses 136 to generate a global transfer function and to perform optimization on the global transfer function. For example, if Melt Pressure to Fill (meltP) was three times more critical than Cycle Time (tcycle)

and Total Cost (totalCost), the user may enter the following relationship in the other optimization field 160.

$$Y = 3(\text{meltP}) + \text{tcycle} + \text{totalCost}.$$

The meltP response has been modified by a weight (e.g., 3) to reflect its importance. The optimization module 22 can then optimize on the variable Y. The user requests this global optimization by defining the global transfer function in the other optimization field 160 and selecting an optimization indicator 161.

Once the factors 134 have been optimized based on the optimization criteria identified by the user, flow proceeds to step 66 where the user can setup visualization of the factors 134 and responses 136 for each material 132. FIG. 12 depicts an exemplary user interface for setting up the visualization. The user can select the materials 132, factors 134 and responses 136 which are to be displayed and select the type of display through a visualization identifier 140. FIG. 13 depicts an exemplary visualization for two materials 132. Each of the responses 136 is plotted against each factor 134 for each material. Since two materials were specified in the visualization setup in FIG. 12, two plots are presented on each graph. The user can select the active material through a drop down menu 133 and the active material (i.e., the material for which the optimization points are shown) is distinguished from other materials (e.g., the active material is shown with a thick line or a different color). Each graph also includes the optimization data entered by the user in the optimization step 64. For example, as shown in the plot of Melt Pressure to Fill (meltP) versus Melt Temperature (meltTemp), a horizontal line is provided at the upper limit of 140 MPa specified by the user. The optimum value for Melt Temperature is shown as a vertical line at 304.45 degrees C. Thus, the user can see the optimum value for the Melt Temperature as determined by the optimization module 22 and the user can see that the Melt Temperature must remain above a certain value (approximately 290 degrees C) to have the Melt Pressure to Fill remain below the upper limit of 140 MPa.

The other plots in FIG. 13 may similarly depict the optimum value for a factor 134, a low limit 92 and a high limit 96.

The invention can be embodied in the form of computer-implemented processes and apparatuses for practicing those processes. The present invention can also be embodied in the form of computer program code containing instructions embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, or any other computer-readable storage medium, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus for practicing the invention. The present invention can also be embodied in the form of computer program code, for example, whether stored in a storage medium, loaded into and/or executed by a computer, or transmitted over some transmission medium, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus for practicing the invention. When implemented on a general-purpose microprocessor, the computer program code segments configure the microprocessor to create specific logic circuits.

While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A method for designing a product, the method comprising:

specifying a plurality of factors (44) related to the product;

specifying a plurality of responses (46) affected by said factors;

performing a design of experiments routine to generate design of experiments data relating at least one factor (44) to at least one response (46);

performing regression to generate a transfer function in response to said design of experiments data;

optimizing said transfer function in response to user-defined optimization criteria to generate an optimized factor and an optimized response; and

displaying said optimized factor and said optimized response.

2. The method of claim 1 further comprising:

specifying a material for the product.

3. The method of claim 2 wherein:

said factors include application factors (72) which are material independent; and

said factors includes manufacturing factors (108) which are material dependent.

4. The method of claim 1 wherein:

said optimizing includes mathematically relating a plurality of transfer functions to define a global transfer function and optimizing said global transfer function.

5. The method of claim 4 wherein:

said mathematically relating a plurality of transfer functions includes assigning a weight to one of said responses, said weight indicating a significance of said response.

6. The method of claim 1 wherein:

said factors (44) include predefined factors.

7. The method of claim 6 wherein:

said factors (44) include user-defined factors (82).

8. The method of claim 1 wherein:

said responses (46) include predefined responses.

9. The method of claim 8 wherein:

said responses (46) include user-defined responses (102).

10. A system for designing a product comprising:

an interface (26) for receiving a plurality of factors (44) related to the product and a plurality of responses (46) affected by said factors;

a design of experiments module (16) for performing a design of experiments routine to generate design of experiments data relating at least one factor (44) to at least one response (46);

a regression module (20) for performing regression to generate a transfer function in response to said design of experiments data;

an optimization module (22) for optimizing said transfer function in response to user-defined optimization criteria to generate an optimized factor and an optimized response; and

a visualization module (24) for displaying said optimized factor and said optimized response.

11. The system of claim 10 wherein:

said interface (26) receives a material for the product.

12. The system of claim 11 wherein:

said factors (44) include application factors (72) which are material independent; and

said factors (44) includes manufacturing factors (108) which are material dependent.

13. The system of claim 10 wherein:

said optimizing includes mathematically relating a plurality of transfer functions to define a global transfer function and optimizing said global transfer function.

14. The system of claim 13 wherein:

said mathematically relating a plurality of transfer functions includes assigning a weight to one of said responses, said weight indicating a significance of said response.

15. The system of claim 10 wherein:

said factors (44) include predefined factors.

16. The system of claim 15 wherein:

said factors (44) include user-defined factors (82).

17. The system of claim 10 wherein:

said responses (46) include predefined responses.

18. The system of claim 17 wherein:

said responses (46) include user-defined responses (102).

19. A storage medium encoded with machine-readable computer program code for designing a product, the storage medium including instructions for causing a computer to implement a method comprising:

receiving a plurality of factors (44) related to the product;

receiving a plurality of responses (46) affected by said factors;

performing a design of experiments routine to generate design of experiments data relating at least one factor (44) to at least one response (46);

performing regression to generate a transfer function in response to said design of experiments data;

optimizing said transfer function in response to user-defined optimization criteria to generate an optimized factor and an optimized response; and

displaying said optimized factor and said optimized response.

20. The storage medium of claim 19 further comprising instructions for causing the computer to implement:

receiving a material for the product.

21. The storage medium of claim 20 wherein:

said factors (44) include application factors (72) which are material independent; and

said factors (44) includes manufacturing factors (108) which are material dependent.

22. The storage medium of claim 19 wherein:

said optimizing includes mathematically relating a plurality of transfer functions to define a global transfer function and optimizing said global transfer function.

23. The storage medium of claim 22 wherein:

said mathematically relating a plurality of transfer functions includes assigning a weight to one of said responses, said weight indicating a significance of said response.

24. The storage medium of claim 19 wherein:

said factors (44) include predefined factors.

25. The storage medium of claim 24 wherein:

said factors (44) include user-defined factors (82).

26. The storage medium of claim 19 wherein:

said responses (46) include predefined responses.

27. The storage medium of claim 26 wherein:

said responses (46) include user-defined responses (102).

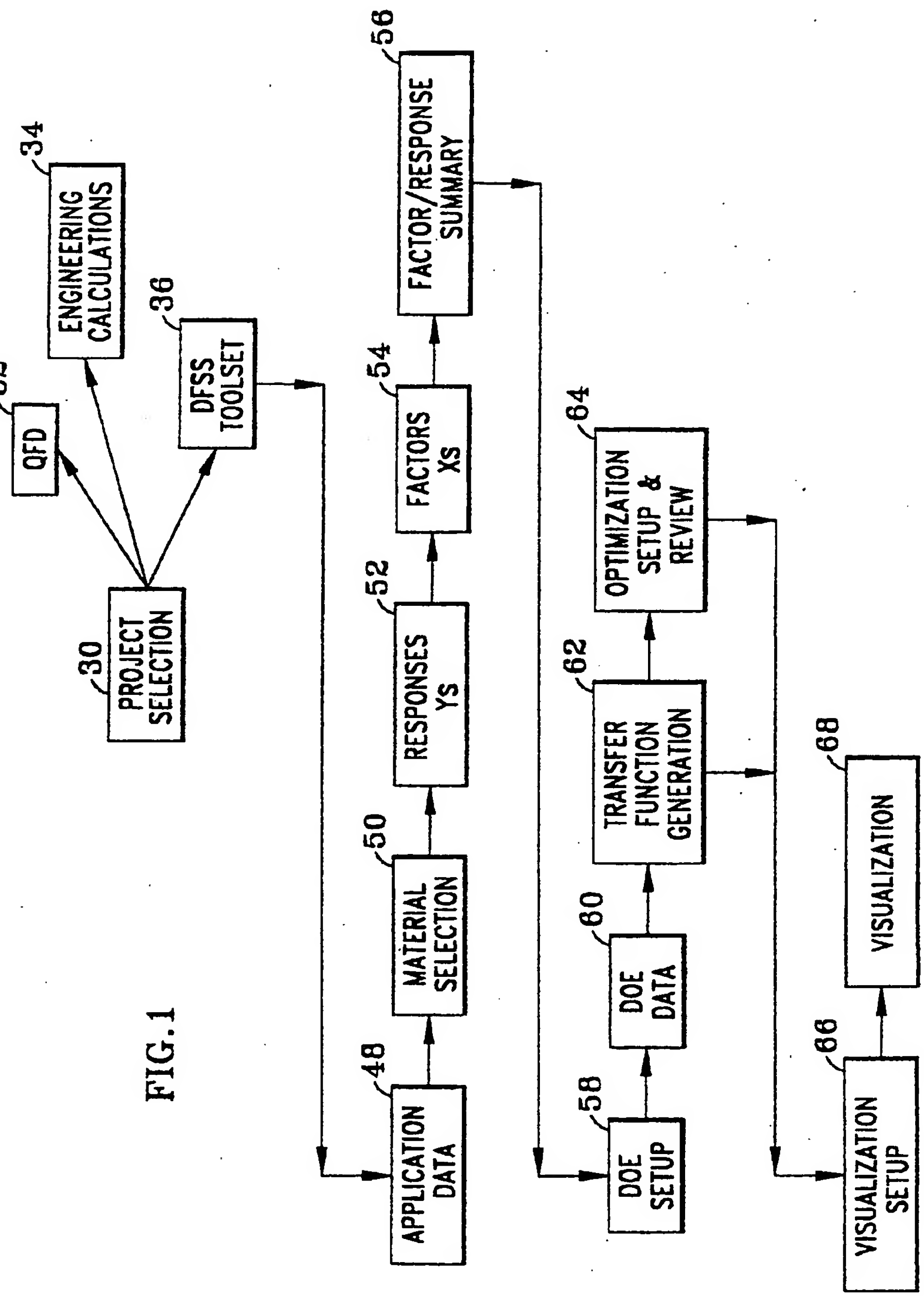

PROJECT SELECTION
30
QFD
32
ENGINEERING CALCULATIONS
34
DFSS TOOLSET
36
APPLICATION DATA
48
MATERIAL SELECTION
50
RESPONSES Ys
52
FACTORS Xs
54
FACTOR/RESPONSE SUMMARY
56
DOE SETUP
58
DOE DATA
60
TRANSFER FUNCTION GENERATION
62
OPTIMIZATION SETUP & REVIEW
64
VISUALIZATION SETUP
66
VISUALIZATION
68

FIG.1

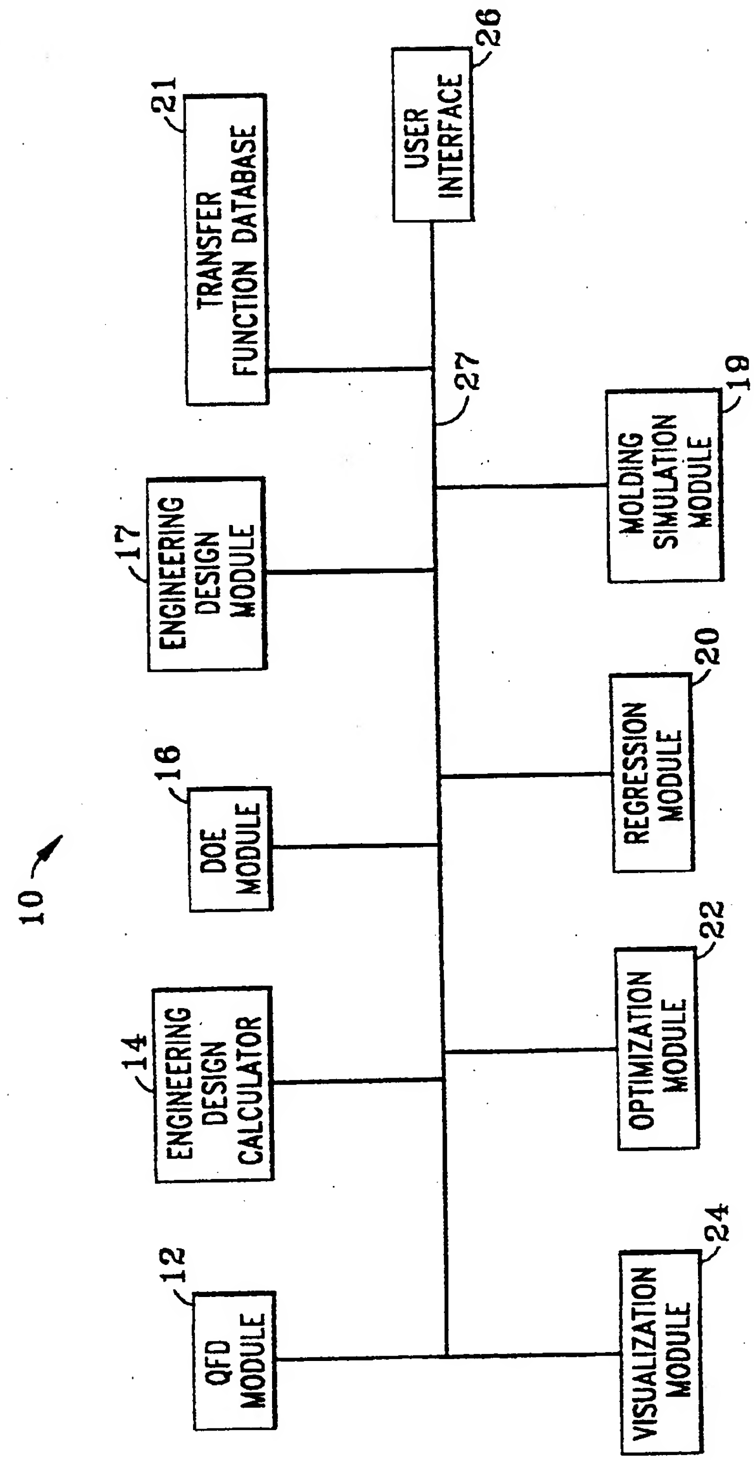

10
QFD MODULE
12
ENGINEERING DESIGN CALCULATOR
14
DOE MODULE
16
ENGINEERING DESIGN MODULE
17
TRANSFER FUNCTION DATABASE
21
USER INTERFACE
26
27
MOLDING SIMULATION MODULE
19
REGRESSION MODULE
20
OPTIMIZATION MODULE
22
VISUALIZATION MODULE
24

FIG.2

42

ENGINEERING CALCULATOR			40	SELECT GEOMETRY	
MATERIAL NAME	LEXAN LS2				
MATERIAL DATABASE	GEP		SELECT MATERIAL BOX	STRIP PLAQUE	DISK
MATERIAL PRICE	$2.20				

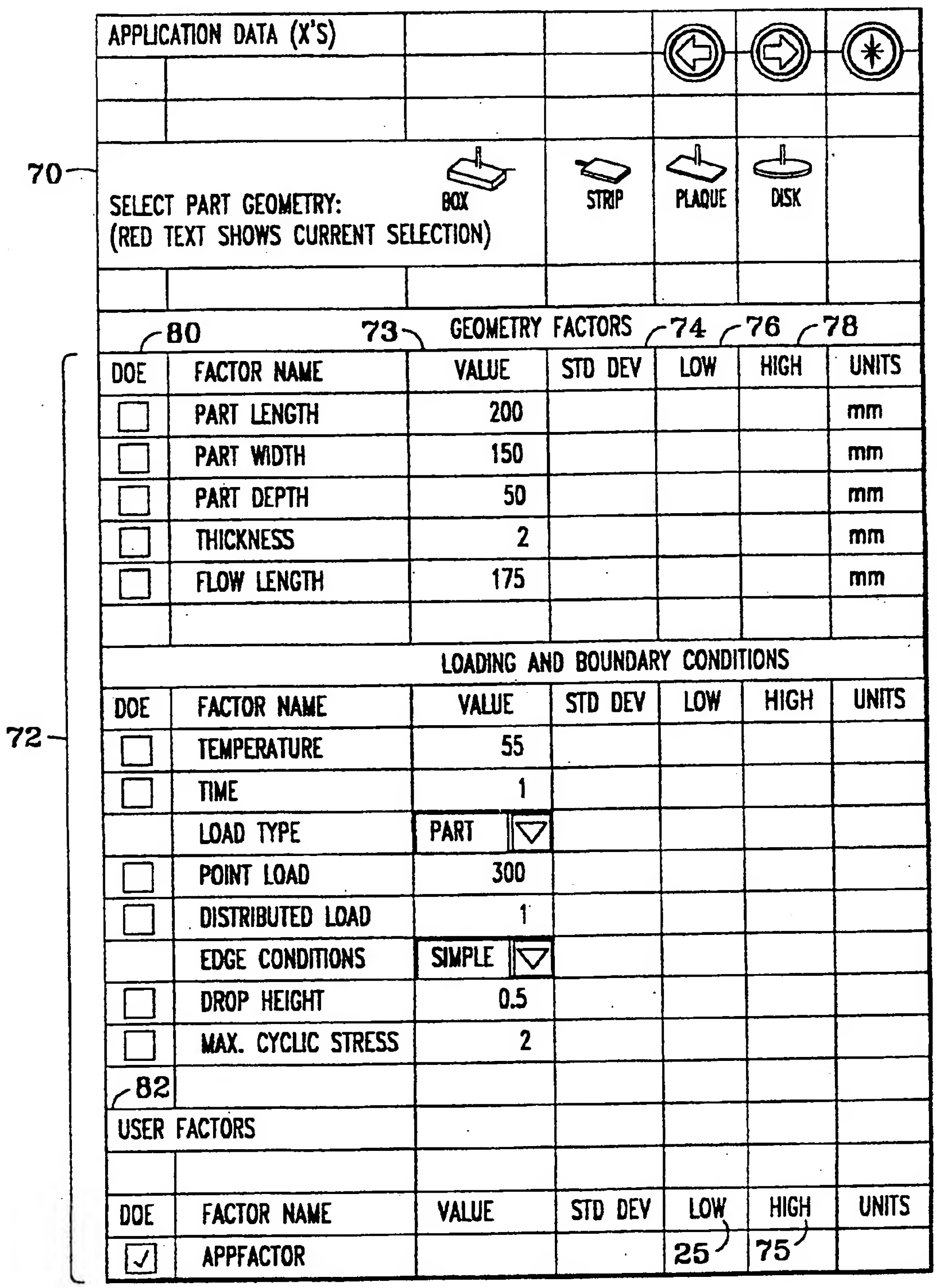
44 — FACTOR (X'S) 45

GEOMETRY X'S		
FACTOR NAME	VALUE	UNITS
PART LENGTH	500	mm
PART WIDTH	250	mm
PART DEPTH	150	mm
THICKNESS	2	mm
FLOW LENGTH	429.5085	mm
LOADING AND BOUNDARY CONDITIONS		
FACTOR NAME	VALUE	UNITS
TEMPERATURE	500	C
TIME	250	HOURS
LOAD TYPE	POINT ▽	
POINT LOAD	300	N
DISTRIBUTED LOAD	1	Pa
EDGE CONDITIONS	SIMPLE ▽	
DROP HEIGHT	0.5	m
MAX. CYCLIC STRESS	2	Mpa
PROCESSING X'S		
FACTOR NAME	VALUE	UNITS
MELT TEMPERATURE	304.45	C
MOLD TEMPERATURE	82.2	C
INJECTION TIME	5.5	sec
PACKING PRESSURE	42.5	Mpa
MOLD OPEN TIME	3	sec
MACHINE X'S		
FACTOR NAME	VALUE	UNITS
MACHINE LABOR RATE	$100.00	$/HR
PRODUCTION VOLUME	100000	PARTS
NUMBER OF TOOLS	1	#
NUMBER OF CAVITIES	2	# /TOOL
TOOL AVAILABILITY	40	HRS/WEEK
TOOL COST	50000	$ / TOOL
MISCELLANEOUS X'S		
FACTOR NAME	VALUE	UNITS
STRAIN TO FAILURE	0.95	

RESPONSES (Y'S) — 46

PERFORMANCE Y'S		
RESPONSE NAME	VALUE	UNITS
DEFLECTION		mm
STRESS	152.713	MPa
EFFECTIVE MODULUS	39.469	MPa
ENERGY ABSORBED	0	BTU
CYCLES TO FAILURE	0	
PROCESSING Y'S		
RESPONSE NAME	VALUE	UNITS
MELT PRESSURE TO FILL	414.02	MPa
INJECTION ENERGY		MPa*S
MAX SHEAR RATE	3791.283	1/S
COOLING TIME	12.39868	SEC
CYCLE TIME	20.89868	SEC
CLAMP FORCE	7848.828	TONS
SHRINKAGE (FLOW)	0.53	%
SHRINKAGE (CROSS-FLOW)	0.53	%
WARP INDEX	0	
PART VOLUME	700	cm^3
PART WEIGHT	0.84	kg
COST Y'S		
RESPONSE NAME	VALUE	UNITS
PRODUCTION TIME	7.256485	WEEKS
PROCESSING COST	0.58	$/PART
MATERIAL COST	1.85	$/PART
TOOLING COST	0.25	$/PART
TOTAL COST	2.68	$/PART

FIG.3



APPLICATION DATA (X'S)
70
SELECT PART GEOMETRY:
(RED TEXT SHOWS CURRENT SELECTION)
BOX
STRIP
PLAQUE
DISK
80
73
GEOMETRY FACTORS
74
76
78
DOE
FACTOR NAME
VALUE
STD DEV
LOW
HIGH
UNITS
PART LENGTH 200 mm
PART WIDTH 150 mm
PART DEPTH 50 mm
THICKNESS 2 mm
FLOW LENGTH 175 mm
LOADING AND BOUNDARY CONDITIONS
DOE
FACTOR NAME
VALUE
STD DEV
LOW
HIGH
UNITS
72
TEMPERATURE 55
TIME 1
LOAD TYPE PART
POINT LOAD 300
DISTRIBUTED LOAD 1
EDGE CONDITIONS SIMPLE
DROP HEIGHT 0.5
MAX. CYCLIC STRESS 2
82
USER FACTORS
DOE
FACTOR NAME
VALUE
STD DEV
LOW
HIGH
UNITS
APPFACTOR
25
75

FIG.4

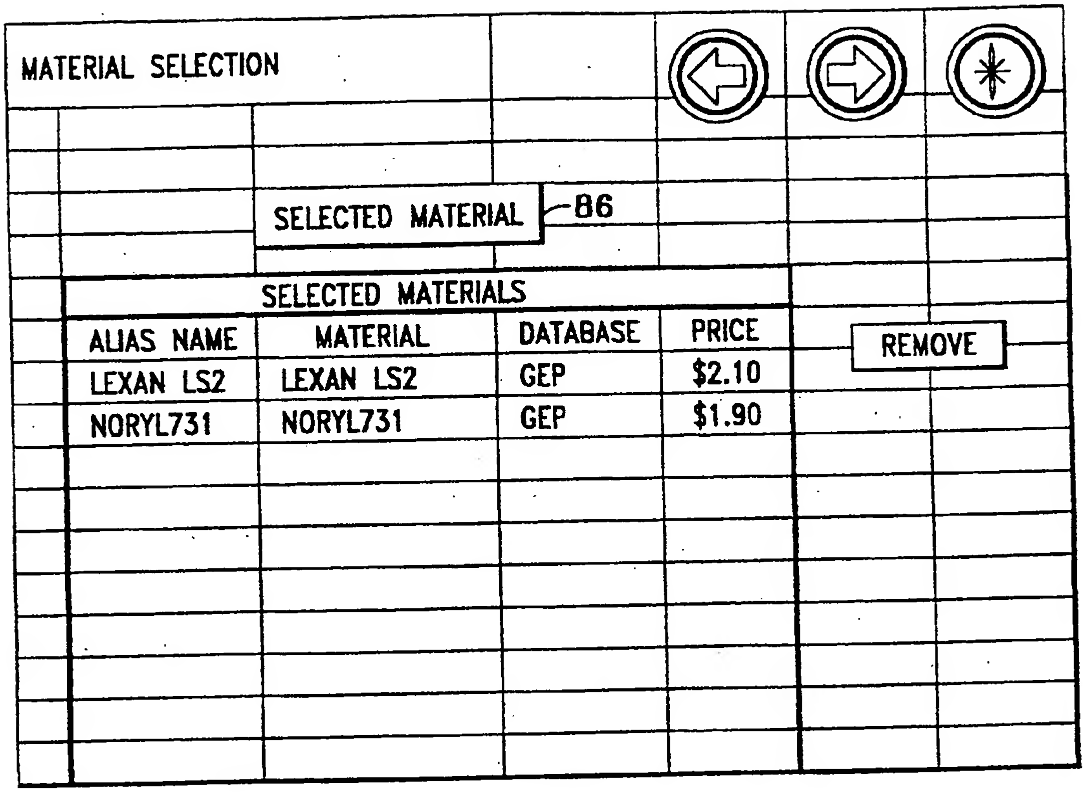

MATERIAL SELECTION
SELECTED MATERIAL
86
SELECTED MATERIALS
ALIAS NAME
MATERIAL
DATABASE
PRICE
REMOVE
LEXAN LS2
LEXAN LS2
GEP
$2.10
NORYL731
NORYL731
GEP
$1.90

FIG.5

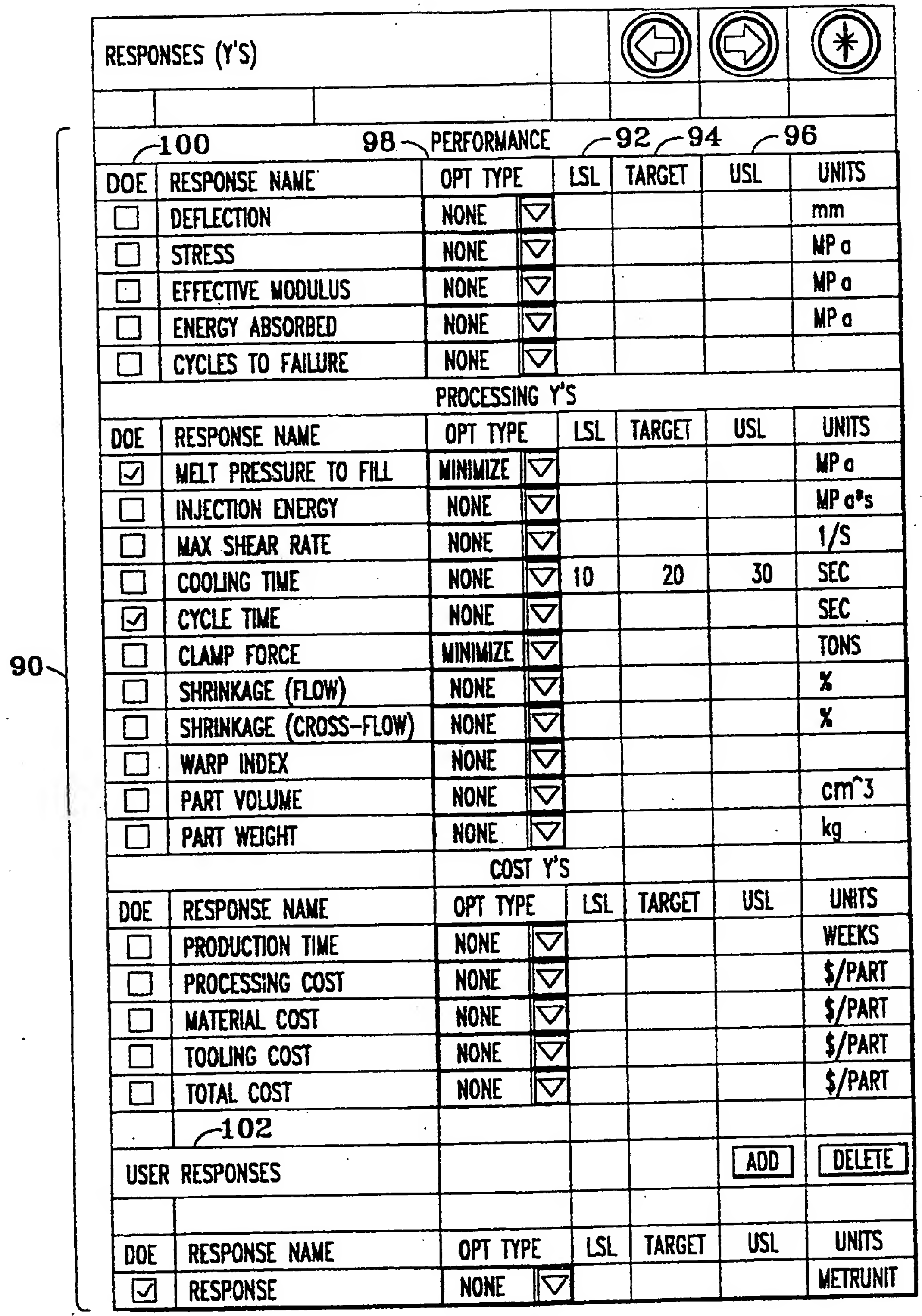

RESPONSES (Y'S)
100
98
PERFORMANCE
92
94
96
DOE
RESPONSE NAME
OPT TYPE
LSL
TARGET
USL
UNITS
DEFLECTION
NONE
mm
STRESS
NONE
MPa
EFFECTIVE MODULUS
NONE
MPa
ENERGY ABSORBED
NONE
MPa
CYCLES TO FAILURE
NONE
PROCESSING Y'S
DOE
RESPONSE NAME
OPT TYPE
LSL
TARGET
USL
UNITS
MELT PRESSURE TO FILL
MINIMIZE
MPa
INJECTION ENERGY
NONE
MPa*s
MAX SHEAR RATE
NONE
1/S
COOLING TIME
NONE
10
20
30
SEC
CYCLE TIME
NONE
SEC
CLAMP FORCE
MINIMIZE
TONS
SHRINKAGE (FLOW)
NONE
%
SHRINKAGE (CROSS-FLOW)
NONE
%
WARP INDEX
NONE
PART VOLUME
NONE
cm^3
PART WEIGHT
NONE
kg
90
COST Y'S
DOE
RESPONSE NAME
OPT TYPE
LSL
TARGET
USL
UNITS
PRODUCTION TIME
NONE
WEEKS
PROCESSING COST
NONE
$/PART
MATERIAL COST
NONE
$/PART
TOOLING COST
NONE
$/PART
TOTAL COST
NONE
$/PART
102
USER RESPONSES
ADD
DELETE
DOE
RESPONSE NAME
OPT TYPE
LSL
TARGET
USL
UNITS
RESPONSE
NONE
METRUNIT

FIG.6

FACTORS (X'S)

MATERIAL: LEXAN LS2

108

116 109 PROCESS FACTORS 110 112 114

DOE	FACTOR NAME	VALUE	STD DEV	LOW	HIGH	UNITS
☑	MELT TEMPERATURE	304.45		293.3	315.6	C
☑	MOLD TEMPERATURE	82.2		71.1	93.3	C
☑	INJECTION TIME	5.5		1	5	SEC
☐	PACKING PRESSURE	42.5		25	50	MP a
	MOLD OPEN TIME	3				SEC

COST FACTORS

DOE	FACTOR NAME	VALUE	STD DEV	LOW	HIGH	UNITS
	MACHINE LABOR RATE	$100.00				$/HR
	PRODUCTION VOLUME	100000				PARTS
	NUMBER OF TOOLS	1				#
	NUMBER OF CAVITIES	2	10	20	30	#/TOOL
	TOOL AVAILABILITY	40				HRS/WEEK
	TOOLING COST	50000				$/TOOL

OTHER FACTORS

DOE	FACTOR NAME	VALUE	STD DEV	LOW	HIGH	UNITS
☐	STRAIN TO FAILURE	0.95				

118

USER FACTORS ADD DELETE

DOE	FACTOR NAME	VALUE	STD DEV	LOW	HIGH	UNITS
☑	MALT FACTOR			20	50	METRUNIT

FIG.7

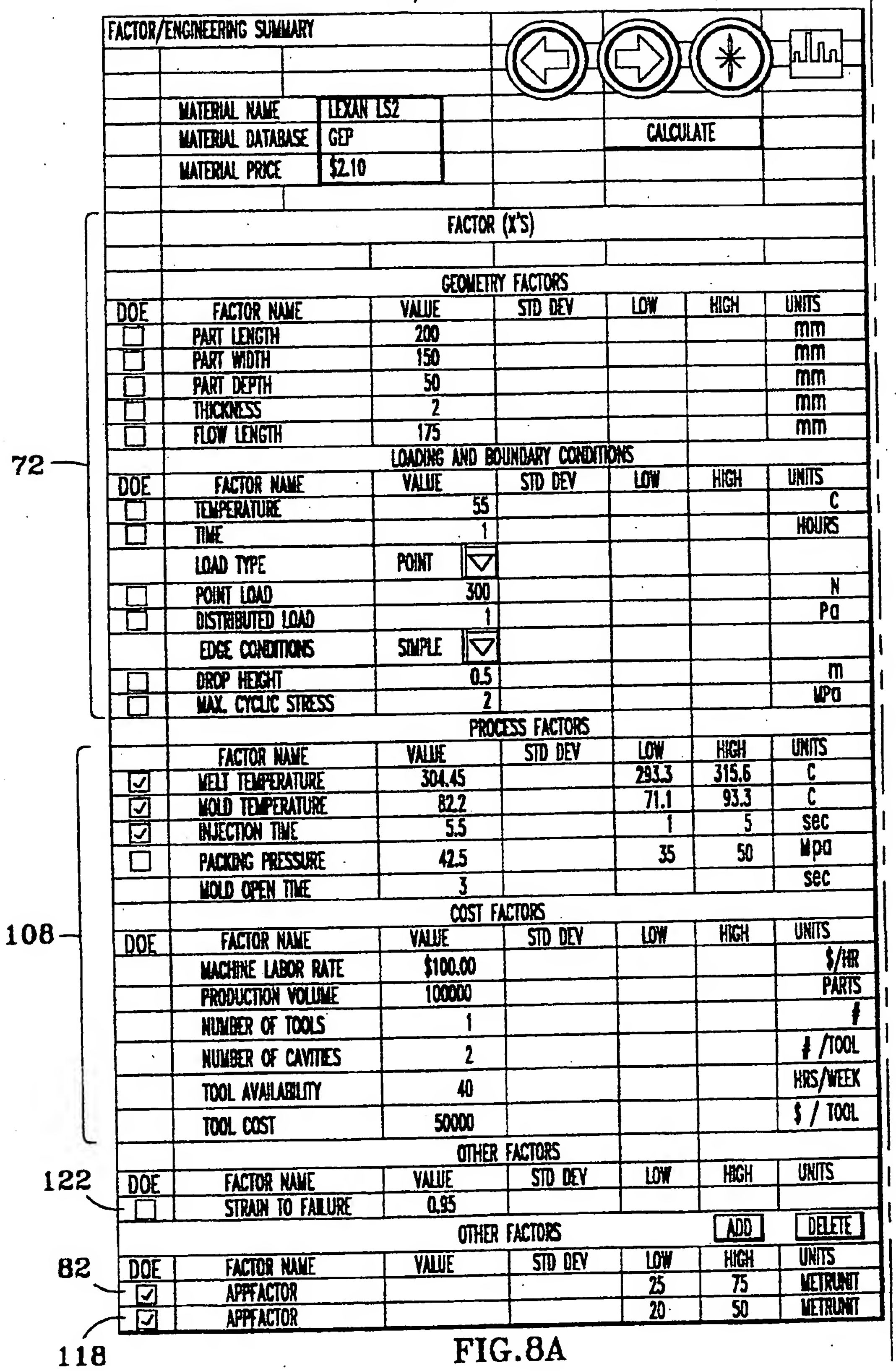

FACTOR/ENGINEERING SUMMARY
MATERIAL NAME
LEXAN LS2
MATERIAL DATABASE
GEP
MATERIAL PRICE
$2.10
CALCULATE
FACTOR (X'S)
GEOMETRY FACTORS
DOE
FACTOR NAME
VALUE
STD DEV
LOW
HIGH
UNITS
PART LENGTH 200 mm
PART WIDTH 150 mm
PART DEPTH 50 mm
THICKNESS 2 mm
FLOW LENGTH 175 mm
LOADING AND BOUNDARY CONDITIONS
TEMPERATURE 55 C
TIME 1 HOURS
LOAD TYPE POINT
POINT LOAD 300 N
DISTRIBUTED LOAD 1 Pa
EDGE CONDITIONS SIMPLE
DROP HEIGHT 0.5 m
MAX. CYCLIC STRESS 2 MPa
PROCESS FACTORS
MELT TEMPERATURE 304.45 293.3 315.6 C
MOLD TEMPERATURE 82.2 71.1 93.3 C
INJECTION TIME 5.5 1 5 sec
PACKING PRESSURE 42.5 35 50 Mpa
MOLD OPEN TIME 3 sec
COST FACTORS
MACHINE LABOR RATE $100.00 $/HR
PRODUCTION VOLUME 100000 PARTS
NUMBER OF TOOLS 1 #
NUMBER OF CAVITIES 2 # /TOOL
TOOL AVAILABILITY 40 HRS/WEEK
TOOL COST 50000 $ / TOOL
OTHER FACTORS
STRAIN TO FAILURE 0.95
OTHER FACTORS
ADD
DELETE
APPFACTOR 25 75 METRUNIT
APPFACTOR 20 50 METRUNIT
72
108
122
82
118

FIG.8A

RESPONSES (Y'S)							
			PERFORMANCE Y'S				
DOE	RESPONSE NAME	VALUE	OPT TYPE	LSL	TARGET	USL	UNITS
☐	DEFLECTION		NONE ▽				mm
☐	STRESS	0.002	NONE ▽				MPa
☐	EFFECTIVE MODULUS	2344.217	NONE ▽				MPa
☐	ENERGY ABSORBED	0	NONE ▽				MPa
☐	CYCLES TO FAILURE	0	NONE ▽				
			PROCESSING Y'S				
DOE	RESPONSE NAME		OPT TYPE	LSL	TARGET	USL	UNITS
☑	MELT PRESSURE TO FILL	178.91	MINIMIZE ▽				MPa
☐	INJECTION ENERGY		NONE ▽				MPa*s
☐	MAX SHEAR RATE	853.8057	NONE ▽				1/S
☑	COOLING TIME	12.39868	NONE ▽	10	20	30	SEC
☐	CYCLE TIME	20.89868	TARGET ▽				SEC
☐	CLAMP FORCE	775.6904	NONE ▽				TONS
☐	SHRINKAGE (FLOW)	0.53	NONE ▽				%
☐	SHRINKAGE (CROSS-FLOW)	0.53	NONE ▽				%
☐	WARP INDEX	0	NONE ▽				
☐	PART VOLUME	130	NONE ▽				cm ^3
☐	PART WEIGHT	0.156	NONE ▽				kg
			COST Y'S				
DOE	RESPONSE NAME		OPT TYPE	LSL	TARGET	USL	UNITS
☐	PRODUCTION TIME	7.256485	NONE ▽				WEEKS
☐	PROCESSING COST	0.58	NONE ▽				$/PART
☐	MATERIAL COST	0.33	NONE ▽				$/PART
☐	TOOLING COST	0.25	NONE ▽				$/PART
☑	TOTAL COST	1.16	NONE ▽				$/PART
			USER RESPONSES			ADD	DELETE
DOE	RESPONSE NAME		OPT TYPE	LSL	TARGET	USL	UNITS
☑	RESPONSE		NONE ▽				METRUNIT

126

90

102

FIG.8B

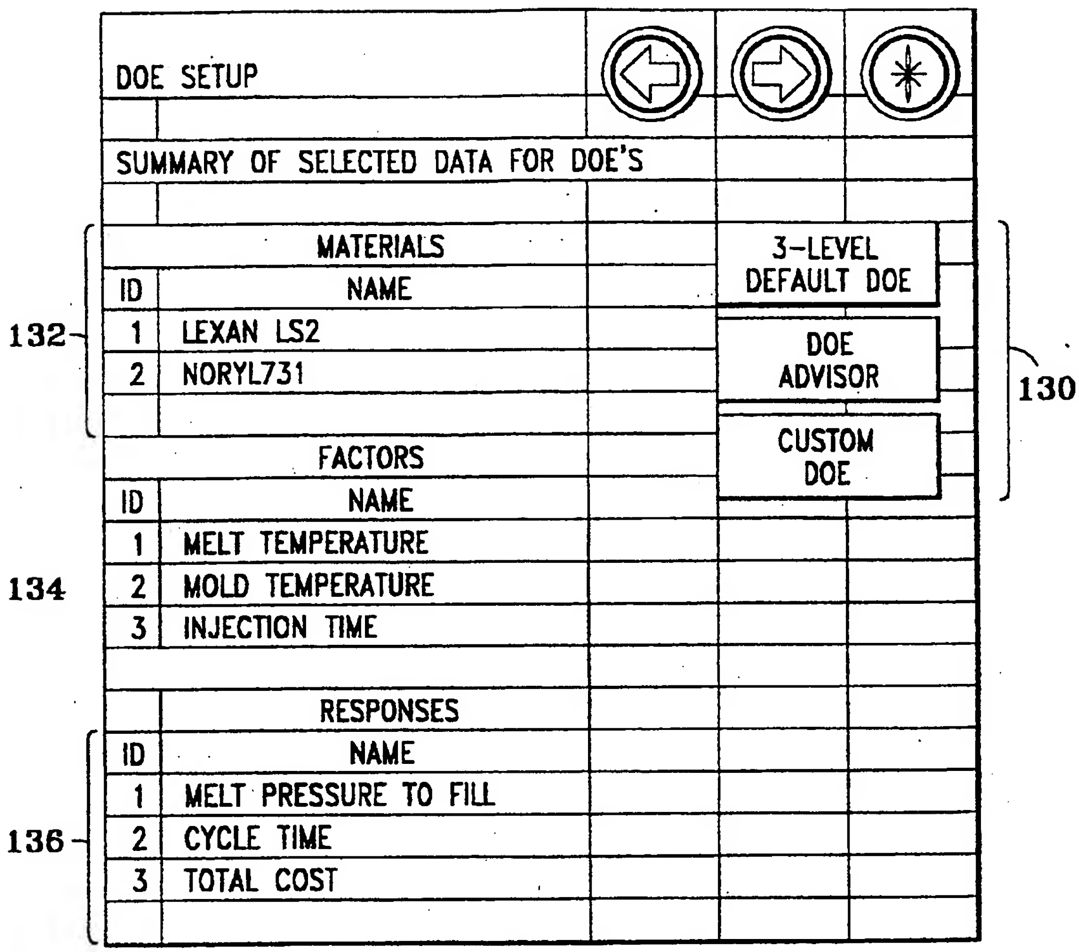

DOE SETUP
SUMMARY OF SELECTED DATA FOR DOE'S
MATERIALS
ID
NAME
1 LEXAN LS2
2 NORYL731
FACTORS
ID
NAME
1 MELT TEMPERATURE
2 MOLD TEMPERATURE
3 INJECTION TIME
RESPONSES
ID
NAME
1 MELT PRESSURE TO FILL
2 CYCLE TIME
3 TOTAL COST
3-LEVEL DEFAULT DOE
DOE ADVISOR
CUSTOM DOE
132
134
136
130

FIG.9

FIG.10

137 PERFORM DOE	139 PERFORM AREA	RUN DOE ALL MATS	REGRESSION			
MATERIAL:	NORYL731 132					
FACTOR (X)	LOW	HIGH	UNITS		RESPONSE (Y)	UNITS
MELT TEMPERATURE	282.2000122	310	C		MELT PRESSURE	MPa
MOLD TEMPERATURE	76.69999695	104.4000015	C		CYCLE	SEC
INJECTION TIME	1	4	SEC		TOTAL COST	$/PART
DOE	CODED	RANDOMIZE	ADD RUNS	ADD REPS	ADD VAL	
MATRIX		134			136	
RUN	MELT TEMP	MOLD TEMP	TINJ	MELTP	TCYCLE	TOTAL COST
1	282.2000122	76.69999695	1	98.08999634	17.80506134	1.01
2	310	76.69999695	1	74.52999878	18.24765015	1.02
3	282.2000122	104.4000015	1	93.19999695	17.30000687	0.99
4	310	104.4000015	1	70.44000244	17.80675888	1.01
5	282.2000122	76.69999695	4	150.9100037	20.80506134	1.09
6	310	76.69999695	4	121.0299988	21.24765015	1.1
7	282.2000122	104.4000015	4	131.8200073	20.30000687	1.08
8	310	104.4000015	4	104.9100037	20.80675888	1.09
9	310	90.54999924	2.5	93.58000183	19.53416443	1.05
10	296.1000061	104.4000015	2.5	101.0599976	19.06257629	1.04
11	296.1000061	90.54999924	4	126.6699982	20.80591011	1.09
12	296.1000061	90.54999924	2.5	120.3899994	19.0616684	1.04
13	296.1000061	76.69999695	2.5	112.0800018	19.53337097	1.05
14	296.1000061	90.54999924	1	83.69999695	17.80591011	1.01
15	296.1000061	90.54999924	2.5	106.5899963	19.30591011	1.05
VALIDATION RUNS:						

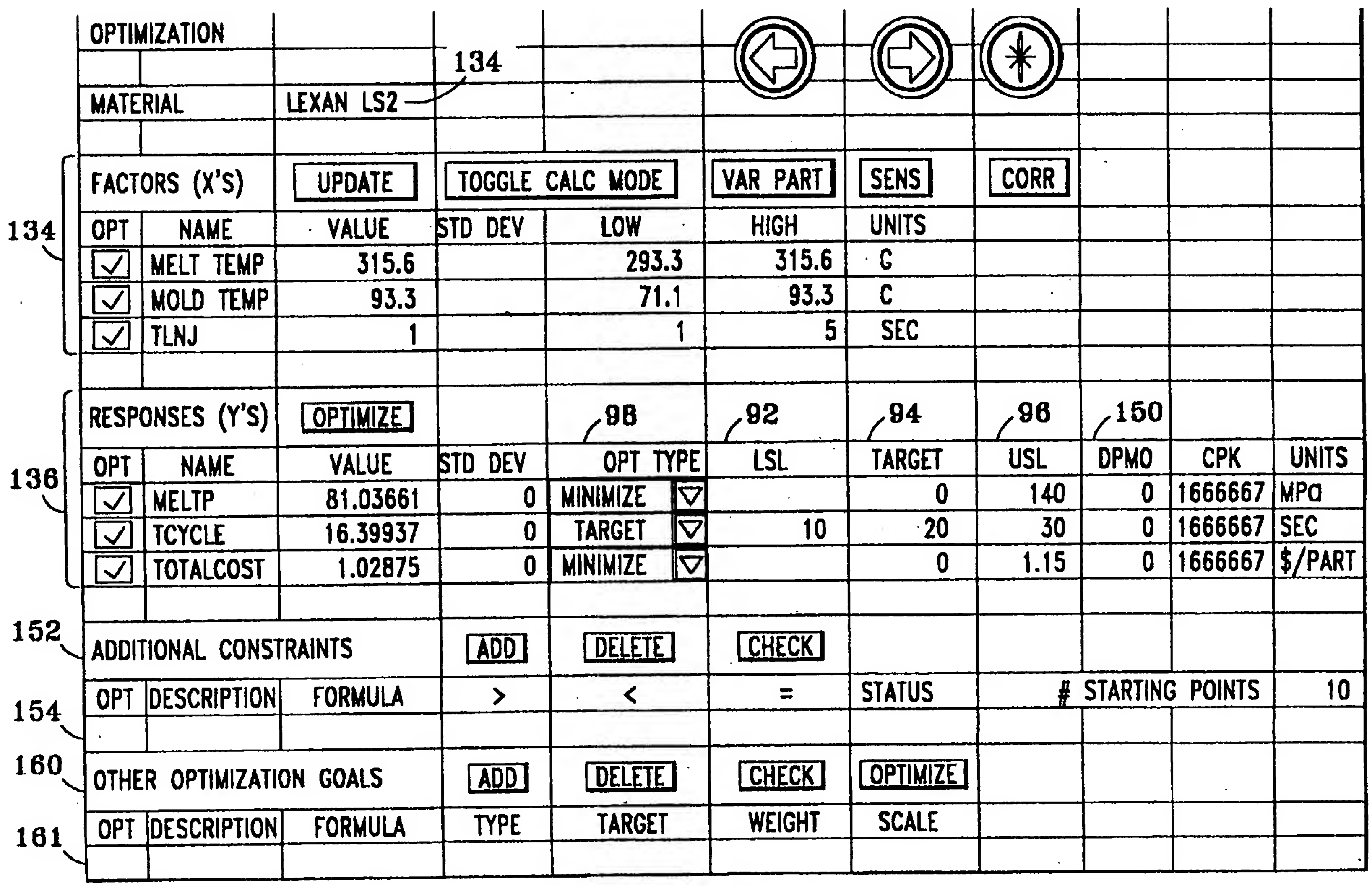

OPTIMIZATION
134
MATERIAL
LEXAN LS2
134
FACTORS (X'S)
UPDATE
TOGGLE CALC MODE
VAR PART
SENS
CORR
OPT
NAME
VALUE
STD DEV
LOW
HIGH
UNITS
MELT TEMP 315.6 293.3 315.6 C
MOLD TEMP 93.3 71.1 93.3 C
TLNJ 1 1 5 SEC
136
RESPONSES (Y'S)
OPTIMIZE
98
92
94
96
150
OPT
NAME
VALUE
STD DEV
OPT TYPE
LSL
TARGET
USL
DPMO
CPK
UNITS
MELTP 81.03661 0 MINIMIZE 0 140 0 1666667 MPa
TCYCLE 16.39937 0 TARGET 10 20 30 0 1666667 SEC
TOTALCOST 1.02875 0 MINIMIZE 0 1.15 0 1666667 $/PART
152
ADDITIONAL CONSTRAINTS
ADD
DELETE
CHECK
154
OPT
DESCRIPTION
FORMULA
>
<
=
STATUS
STARTING POINTS
10
160
OTHER OPTIMIZATION GOALS
ADD
DELETE
CHECK
OPTIMIZE
161
OPT
DESCRIPTION
FORMULA
TYPE
TARGET
WEIGHT
SCALE

FIG.11

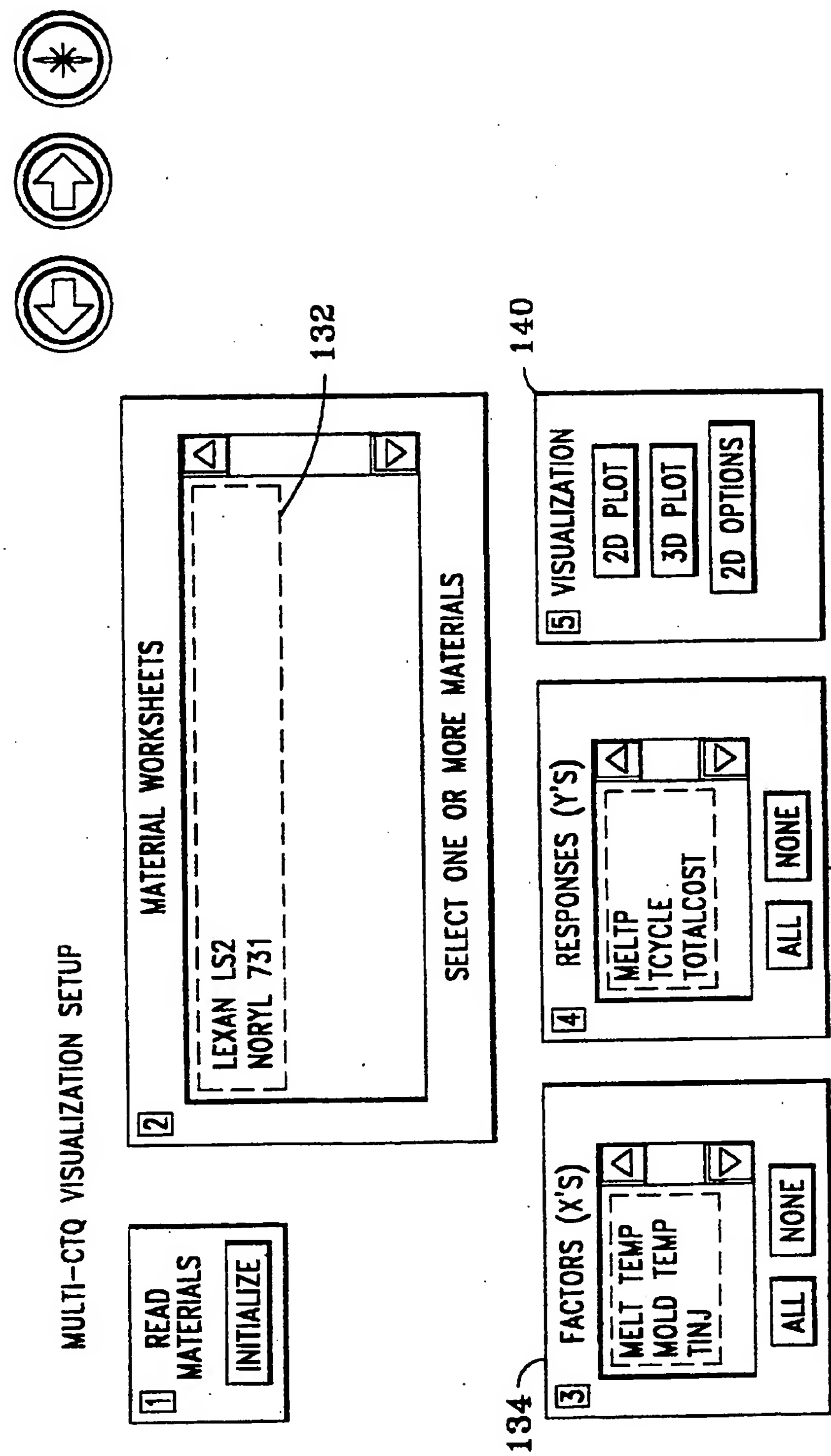

MULTI-CTQ VISUALIZATION SETUP
1 READ MATERIALS
INITIALIZE
2 MATERIAL WORKSHEETS
LEXAN LS2
NORYL 731
SELECT ONE OR MORE MATERIALS
132
3 FACTORS (X'S)
MELT TEMP
MOLD TEMP
TINJ
ALL
NONE
134
4 RESPONSES (Y'S)
MELTP
TCYCLE
TOTALCOST
ALL
NONE
136
5 VISUALIZATION
2D PLOT
3D PLOT
2D OPTIONS
140

FIG.12

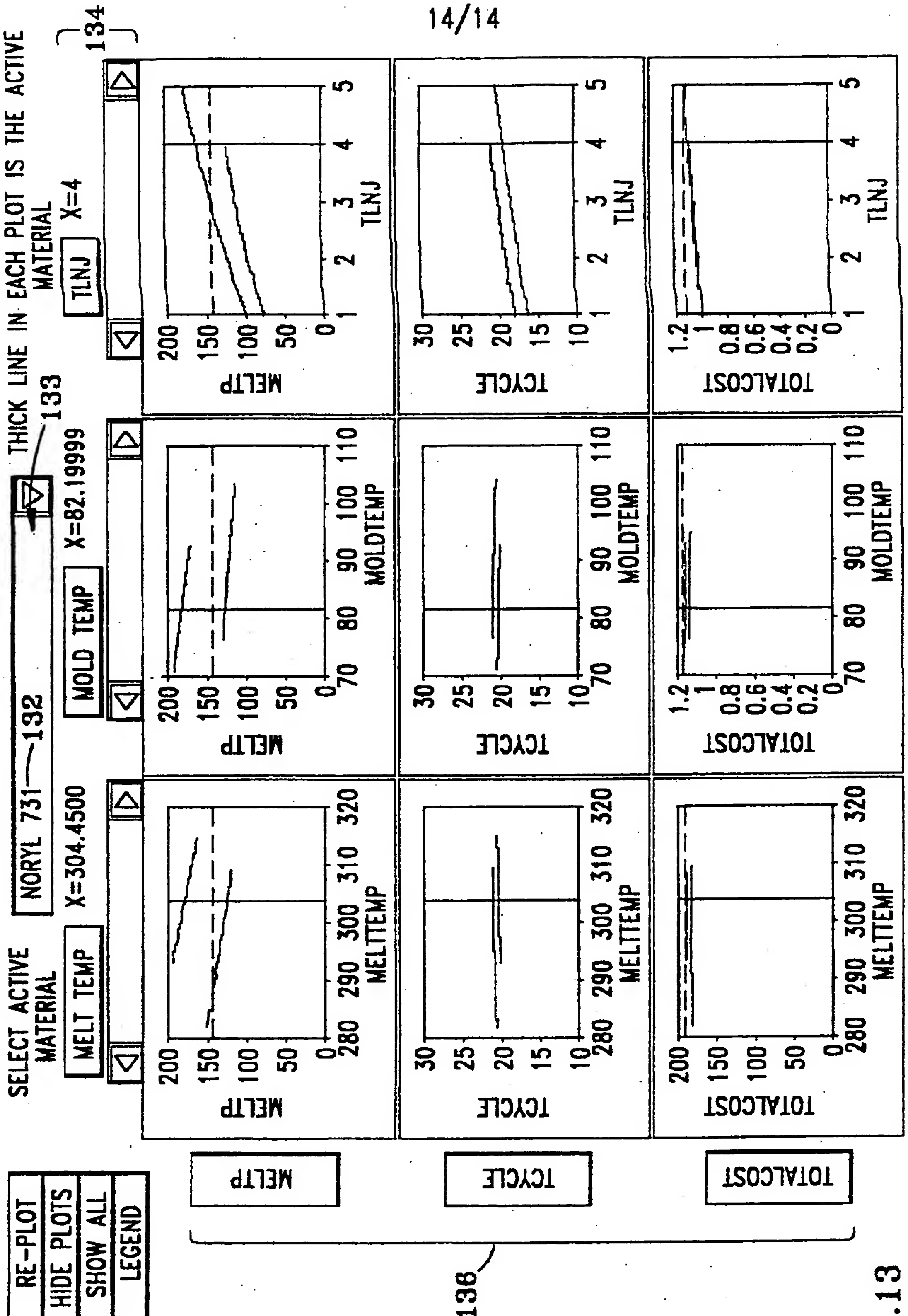

RE-PLOT
HIDE PLOTS
SHOW ALL
LEGEND
SELECT ACTIVE MATERIAL
NORYL 731
132
133
THICK LINE IN EACH PLOT IS THE ACTIVE MATERIAL
134
MELT TEMP
X=304.4500
MOLD TEMP
X=82.19999
TLNJ
X=4
MELTP
TCYCLE
TOTALCOST
MELTTEMP
MOLDTEMP
TLNJ
136

FIG.13